N72-15098

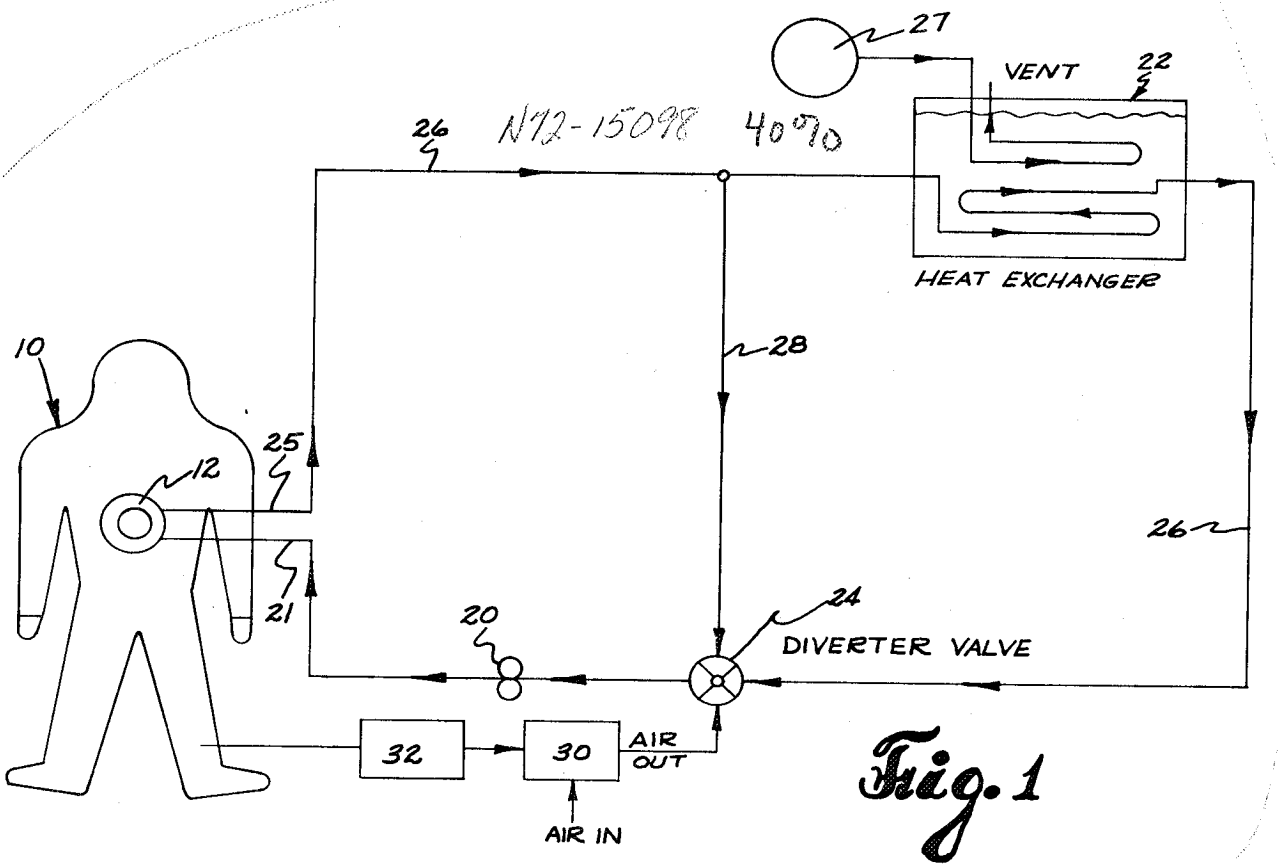

Fig. 1

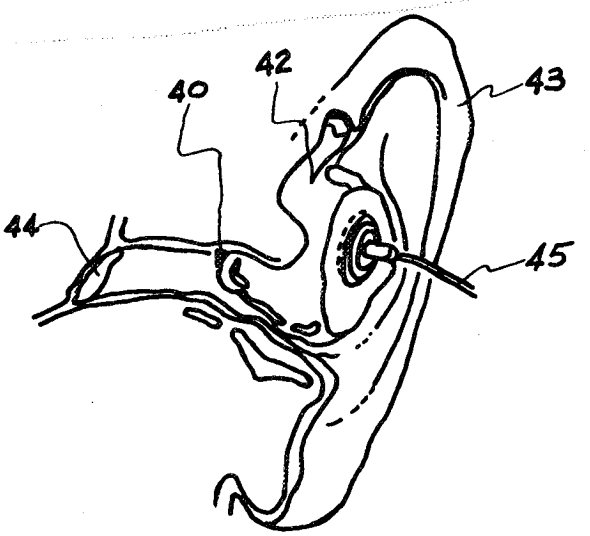

Fig. 2

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MSC-13917-1

N72-15096

NASA CASE NO. MSC-13917-1

PRINT FIG. 1

NOTICE

The invention disclosed in this document resulted from research in aeronautical and space activities performed under programs of the National Aeronautics and Space Administration. The invention is owned by NASA and is therefore available for licensing in accordance with the NASA Patent Licensing Regulation (14 Code of Federal Regulations 1245.200).

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AUTOMATIC CONTROL OF LIQUID COOLING GARMENT BY CUTANEOUS AND EXTERNAL AUDITORY MEATUS TEMPERATURES

The invention relates to an automatic control apparatus for a liquid cooled spacesuit which maintains the temperature of the wearer at levels suitable for his actual physiological needs during varying periods of work and rest. The apparatus frees the crewman from the task of manual control and the problems incumbent with the possibility of premature or excessive cooling and insufficient cooling associated therewith.

The invention is based on findings that change in mean body temperature is an index of heat tolerance since, under transient heat loads, mean body temperature rises as a linear function of heat stress. Accordingly, the apparatus of the present invention controls the temperature of the inlet water to the garment responsive to mean body temperature and its time rate of change. The cooling system includes a diverter valve 24 which is operated by an electropneumatic transducer 30 in response to control signals from controller 32. Temperature input signals are supplied to the controller 32 from temperature sensors attached to the wearer at the ear canal, shoulder, chest, bicep, and lower abdomen. Changes in temperatures are electronically amplified, summed, and converted to a diverter valve command proportional to the deviation of the summed signal from a set point value and to the rate of change of the summed signal from its set point.

The novelty of the invention lies in the combination of elements to provide a control for regulating the inlet water temperature of a liquid cooling garment which is automatically responsive to actual physiological needs of the wearer as measured by his mean body temperature and its time rate of change.

Inventor: Clay W. G. Fulcher [redacted]

Employer: General Electric Co. (Contract NAS 9-10963)
Apollo and Ground Systems - Space Division

~~Initial Evaluator: James M. Waligora~~

Filed: Nov. 12, 1971

Serial No.: 198,355

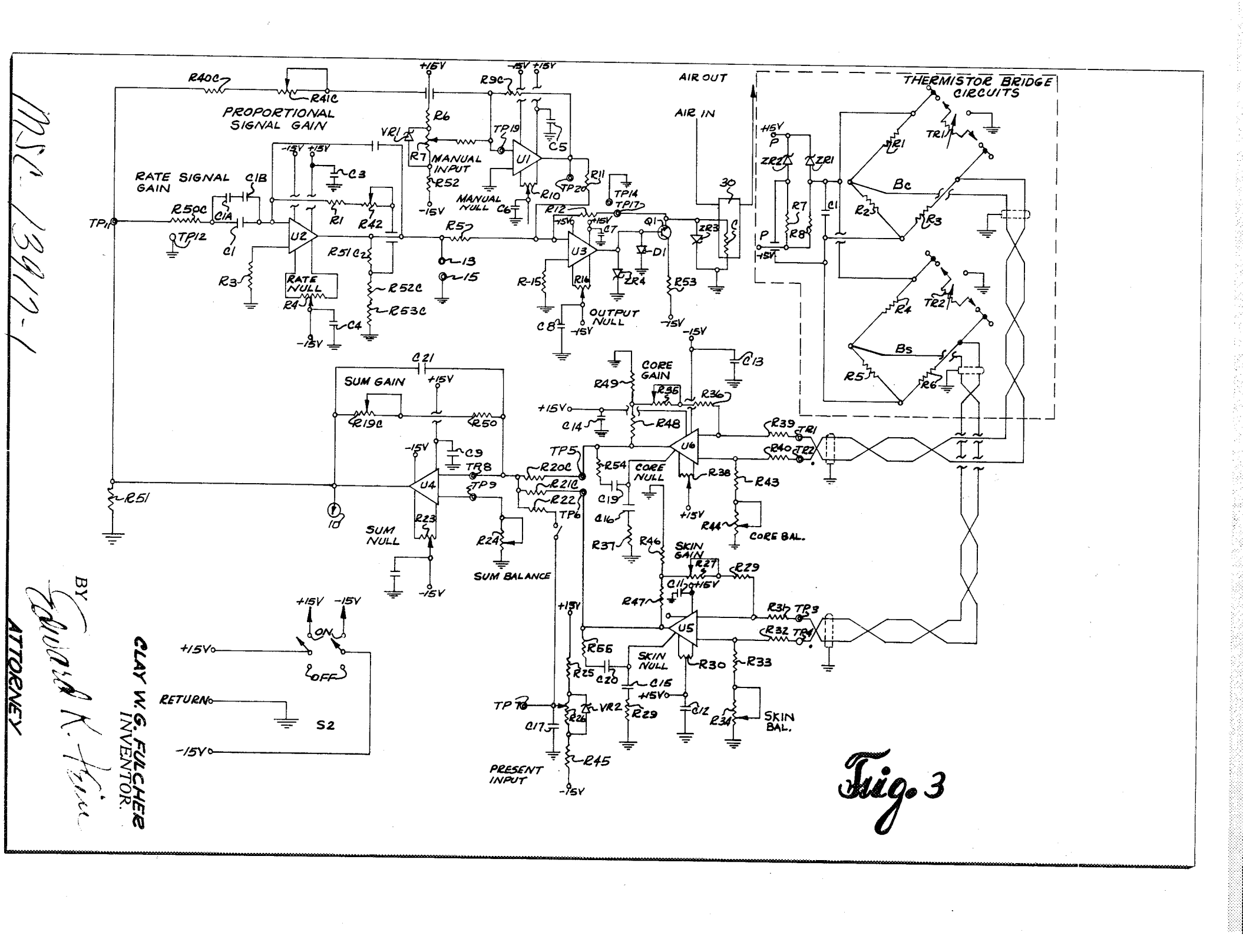

Fig. 3

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NASA Case MSC-13917-1

APPLICATION FOR LETTERS PATENT

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT Clay W. G. Fulcher, a citizen of the United States of America residing at Houston, Texas, has invented certain new and useful improvements in AUTOMATIC CONTROL OF LIQUID COOLING GARMENT BY CUTANEOUS AND EXTERNAL AUDITORY MEATUS TEMPERATURES, of which the following is a specification:

ABSTRACT OF THE DISCLOSURE

Automatic control apparatus for a liquid cooling garment responsive to actual physiological needs during work and rest periods of a man clothed in the liquid cooling garment. Four skin temperature readings and a reading taken at the external portion of the auditory meatus are added and used as the control signal for a temperature control valve regulating inlet water temperature for the liquid cooling garment. The control apparatus may comprise electronic circuits to which the temperatures are applied as control signals and an electro-pneumatic transducer attached to the control valve.

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under NASA contract and is subject to the provisions of section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to apparatus for maintaining the temperature of the human body at levels suitable for the physiological performance required. In particular, it concerns apparatus for controlling the environment of an individual in a closed space, such as by controlling the inlet liquid temperature of a liquid cooling garment.

The invention is particularly directed to temperature control of liquid cooling garments to be used by astronauts

in extravehicular activity. It may also be useful in controlling body temperature in hospital intensive care units or in the treatment of patients suffering from diseases characterized by high fevers.

2. Brief Description of the Prior Art

In the past few years man has made great strides in exploring outer space. The NASA space program has been characterized by continuous and sometimes spectacular advances. Of course, many problems have been encountered in such a program.

One such problem, recognized in the Gemini space program, was the moderate loss of exercise capacity and high metabolic cost of extravehicular activity in the zero gravity environment. It was observed that astronauts were unable to judge their own body thermal state when working in reduced gravity space environments, particularly when extravehicular. The Gemini spacesuit was gas-cooled and was designed for lower levels of metabolic heat production than the system was subjected to during some extravehicular activities. Complications encountered included heavy sweating and visor fogging.

Recognition of the deficiencies of gas-cooled suits resulted in the design of liquid cooling garments which are now used in the Apollo space program. The present Apollo garment features a network of polyvinyl chloride tubing stitched to the inside of a long sleeved undergarment worn by the crewman beneath his pressure suit. A continuous flow of temperature controlled water is supplied through the liquid cooling garment by the Apollo Portable Life Support System. Temperature control of the inlet water to the liquid cooling garment is achieved using a manually controlled three-position valve.

Manual control of pressure suit cooling has proven to be adequate during Apollo flights. However, test results have suggested a need for improved cooling control. Premature or excessive cooling causes cutaneous vasoconstriction and sensations of chilling, combined with subjective feelings of excessive internal heat buildup sometimes accompanied by heavy sweating and/or cramping of muscles. If insufficient cooling is supplied, or if sufficient cooling is not supplied in time, heat storage begins and sweating and discomfort build up quickly. In addition to providing more optimum cooling at all times, automatic control of cooling would free the crewman of one additional task. It is very likely that some form of automatic control of pressure suit cooling will be used in future space mission extravehicular activities.

Several methods of automatically controlling the temperature of liquid cooled clothing have been investigated. One method proposed continuously monitors oxygen consumption as a signal to control cooling. Another is based upon change in cooling water temperature across the man with a skin temperature feedback; another upon heart rate with feedback proportional to change in cooling water temperature across the man; and another on heart rate alone. See Webb, Paul; Troutman, S. J., Jr.; and Annis, J. F., "Automatic Cooling in Water-Cooled Spacesuits", Aerospace Med. 41(3): 269-277. None of these methods has been found to be completely satisfactory. Reliable achievement of subjective body comfort with an automatic device is most difficult to obtain due to complexities of the human body, many of which are not well understood.

SUMMARY OF THE INVENTION

In the present invention, control apparatus is provided for regulating the inlet water temperature for a liquid cooling garment. The control is automatically responsive to actual physiological needs during work and rest periods. The temperature of the wall of the external auditory meatus and four averaged, unweighted skin temperatures are used as input signals to an electro-pneumatic transducer to control a diverter valve in the liquid cooling loop of the liquid cooling garment.

Investigations have concluded that change in mean body temperature is an effective index of heat tolerance since, under transient heat loads, mean body temperature rises as a linear function of heat stress. Consideration of the physiological functions of thermal regulation, man's responses to work under different environmental conditions, and related data leads to the conclusion that reliable control of man's environment in a liquid cooling garment should be keyed to minimizing heat stress, changes of which are reflected by changes in mean body temperature. Such control is based on actual physiological needs, without sensitivity to emotions and other variables which indirect methods are subject to. Some anticipation is also needed in the cooling control to counter thermal inertia of the human body. Such inertia can lead to build up of stored heat and sweating if cooling is delayed sufficiently after onset of work, for example. Thus, the control apparatus of the present invention is designed to control liquid cooling garment inlet water temperature based upon mean body temperature and its time rate of change.

BRIEF DESCRIPTION OF THE DRAWINGS

In the description which follows reference will be made to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a cooling system for controlling the inlet temperature of the cooling fluid in a liquid cooling garment according to a preferred embodiment of the invention;

Fig. 2 is a schematic of an ear mold and thermistor used to measure temperature of the ear canal in the present invention; and

Fig. 3 is an electrical schematic diagram of a controller for use with the present invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to Fig. 1, there is shown a liquid cooling garment, generally designated by the reference numeral 10, which might be used by an astronaut. Connected by a suitable connector 12 to the garment is a liquid cooling system for circulating cooled liquid through the garment for cooling a man according to actual physiological needs.

The cooling system may comprise a circulating pump 20, a heat exchanger 22 and a diverter valve 24 connected in a fluid loop 26. A bypass line 28 is provided in the loop 26 connecting the inlet side of the heat exchanger 22 with the diverter valve 24. The diverter valve 24 may be connected to an electro-pneumatic transducer 30 for operation of the diverter valve 24 according to control signals from a controller 32. If desired, different means, other than an electro-pneumatic transducer, may be used to actuate the diverter valve 24. Temperature input signals are supplied

to the controller 32 from temperature indicators (not shown) attached to the body of the wearer of the liquid cooling garment 10. The controller 32 and temperature indicators will be more fully described hereafter.

In operation, a cooled fluid enters the garment 10 by way of the inlet 21 and connector 12 where it absorbs metabolic heat given off by the wearer. The heated fluid is then returned to the cooling loop 26, via connector 12 and outlet 25, where at least a part of the heated fluid is circulated through the heat exchanger 22. A source of refrigerant 27, such as liquid nitrogen, may be used as an exchange fluid in the heat exchanger 22. Depending on signals from controller 32, the electro-pneumatic transducer 30 positions diverter valve 24 to allow passage of some of the heated fluid through bypass line 28. The diverter valve is thus positioned so that the proper proportion of heated fluid and cooled fluid from the discharge side of heat exchanger 22 is combined for recirculation through the cooling garment 10. The diverter valve 24 can be provided with manual adjustments, if desired, for emergency use or fine adjustment for the individual characteristics of the particular person wearing the garment 10.

As previously stated, it has been determined that the mean body temperature is an effective index of heat tolerance. There are many different "core" or "central" temperature measurements in the human body and the same applied to skin temperature. They are different not only in value, but they respond in different ways and with different rates to disturbance functions such as work, external cooling, and other factors. Rectal temperature has been used in estimating mean body temperature, but rectal temperature instrumentation

promotes a feeling of discomfort and introduces unique design problems in providing flight equipment. Other methods have used the tympanic membrane, external auditory meatus and oral temperatures for assessing heat stress in humans. For an example of one of such measurements, see United States Patent No. 3,054,397 to Benzinger. Other possibilities exist for measuring central temperatures but they are not practical for use in space activities.

Ear canal temperature measurement is more comfortable than either tympanic membrane or rectal measurements, and more reliable than oral measurements which are affected by respiration and talking. As illustrated in Fig. 2, the present invention utilizes a thermoelectric device, such as a thermistor 40 or a thermocouple which may be attached to an ear mold 42 for placement in the ear 43. The thermistor 40 is placed for measuring the temperature of the external meatus and is therefore away from the tympanic membrane 44. An electrical lead wire 45 connects the thermistor 40 to an electronic controller (32 in Fig. 1) to be described hereafter.

In the present invention, average skin temperature is also supplied to the controller. For operational reasons, it is desirable to minimize the number of skin sensors, and for the present invention, four such sensors have been arbitrarily selected. Convenient locations are the right shoulder, right chest, right bicep, and right lower abdomen. Of course, other locations and numbers of sensors could be used.

Referring now to Fig. 3, an electrical system for the controller 32 will be described in conjunction with electropneumatic transducer 30. The controller may comprise temperature sensing bridges B_c amd B_s, amplifiers U1, U3, U4, U5

and U6, differentiator U2 and the current-to-air transducer 30. Power for the thermistor bridge circuits B_c and B_s is obtained from negative and positive 15-volt regulated power supply P-P and is further conditioned by diodes ZR1 and ZR2 and resistors R7 and R8 until 10 volts D.C. is provided to each bridge.

The temperature sensing circuit is composed of two bridges, a core bridge B_c and a skin bridge B_s. Core bridge output is designed to go positive if the astronaut's body temperature exceeds 98.6°F and negative if it drops below 98.6°F. Skin bridge output is designed to go positive if the astronaut's skin temperature exceeds 91.2°F and negative if it drops below 91.2°F. In other words, the core bridge is designed to balance at 98.6°F and the skin bridge is designed to balance at 91.2°F. The core bridge B_c comprises the three resistors R1, R2, R3 and a single thermistor TR1 attached to the ear mold as shown in Fig. 2. The skin bridge comprises resistors R4, R5, R6 and four thermistors TR2 connected in series. These thermistors TR2 are attached to the skin as previously described. Outputs from the bridges B_c and B_s are applied to bridge and summing amplifier circuits as shown.

U5 and U6 are high input impedance, stable, operational amplifiers used for amplifying the temperature sensing bridge outputs. Feedback controlling potentiometers R35 and R27 are provided so that the gain of each amplifier can be adjusted, say between X5 and X15. Potentiometers R34 and R44 are used to balance the input impedance of each bridge amplifier and to minimize drift. Resistance values of each may be chosen so that the circuit is balanced when their dial readings are the same as their respective gain controls R27 and R35.

Outputs from the bridge amplifiers U5 and U6 are coupled through resistors R20C and R21C into summing amplifier U4. U4 is a stable operational amplifier whose output is the function of the inputs through resistors R20C, R21C, R22 and the gain setting potentiometer R19. Potentiometer R19 may be selected so that when there is a preset input through resistor R22, gain may be selected from say X6 to X9.33. Preset input through resistor R22 is an offset adjustment to permit bridge outputs to be zeroed for each astronaut, assuming all do not have body and skin temperatures of 98.6°F and 91.2°F at ambient conditions and thermal equilibrium. Negative and positive inputs are provided for both higher and lower temperatures. This may be accomplished through a voltage divider network consisting of resistors R25, R26, R45 and Zener diode VR2. The summing balance potentiometer R24 minimizes drift.

Outputs from the summing amplifier U4 are fed to the circuits U1 and U2. U2 is used as a differentiator. U1 may have a gain capability of X1 to X6. The output of differentiator U2 is applied to a summing driver circuit U3. U3 sums the rate of temperature signal change from U2 and a manual override input from U1 plus a temperature proportional signal from U1. The manual input provides an astronaut override capability. U3 provides the drive current to power transistor Q1 and has unity gain between its input and the emitter of transistor Q1. Diode ZR4 limits the output of Q1 to minus 10 volts peak and diode D1 clamps it to prevent a positive output.

Transistor Q1 provides the power gain (10 ma to 50 ma) necessary to drive the current-to-air transducer 30. Manual input is required to set the initial conditions of 10

milliamperes. Diode ZR3 protects the transducer from extreme currents by holding a 9.1 volt maximum across the load coil C.

Following is an electrical parts list for the electrical components shown in Fig. 3. Each part is identified by the reference letters and numerals shown in Fig. 3.

ELECTRICAL PARTS DATA LIST

Reference Number	Part Name	Rating-Remarks
R30	Pot. Trim	100K Bourns 3052P
R38	Pot. Trim	100K Bourns 3052P
R23	Pot. Trim	10K Bourns 3052P
R4	Pot. Trim	"
R10	Pot. Trim	"
R16	Pot. Trim	"
R35	Pot. 10 Turn	500K IRC HD150
R44	Pot. 10 Turn	500K IRC HD150
R27	Pot. 10 Turn	500K IRC HD150
R34	Pot. 10 Turn	500K IRC HD150
R39	Resistor 1/8w	499K 1% RN550 IRC CEA T-0
R40	Resistor 1/8w	499K 1% RN550 IRC CEA T-0
R31	Resistor 1/8w	499K 1% RN550 IRC CEA T-0
R32	Resistor 1/8w	499K 1% RN550 IRC CEA T-0
R36	Resistor 1/8w	249K 1% RN55D IRC CEA T-0
R28	Resistor 1/8w	249K 1% RN55D IRC CEA T-0
R33	Resistor 1/8w	255K 1% RN55D IRC CEA T-0
R43	Resistor 1/8w	255K 1T RN55D IRC CEA T-0
R37	Resistor 1/2w	27 1/4 5% carbon
R29	Resistor 1/2w	27 1/4 5% carbon
C15	Capacitor	.033 50V 10% Aerovox MC605A 102RK

Reference Number	Part Name	Rating-Remarks
C16		.033 50V 10% Aerovox MC605A 102RK
R20	Resistor 1/4w	3010 RN60 B/D IRC CEB T-0
R22	Resistor 1/4w	3010 RN60 B/D IRC-CEB T-0
R25	Resistor 1/4w	750 RN60 B/D IRC CEB T-0
R45	Resistor 1/4w	750 RN60 B/D IRC CEB T-0
VR2	Zener diode	IN965B TI 15V 400MW
S_1	Switch	Toggle C&K Components, Inc. 7101
R19	Trim Pot. 10T	25K IRC-HD150
R24	Trim Pot. 10T	2.5K IRC HDL50
C17	Capacitor	.01mf CR05-06 Aerovox MC51C103RK
C11	Capacitor	.01mf CR05-06 Aerovox MC51C103RK
C13	Capacitor	.01mF CR05-06 Aerovox MC51C103RK
C14	Capacitor	.01mf CR05-06 Aerovox MC51C103RK
C12	Capacitor	.01mf CR05-06 Aerovox MC51C103RK
C10	Capacitor	.01mf CR05-06 Aerovox MC51C103RK
C3	Capacitor	.01mf CR05-06 Aerovox MC51C103RK
C4	Capacitor	.01mf CR-5-06 Aerovox MC51C103RK
C5	Capacitor	.01mf CR-5-06 Aerovox MC51C103RK
U1	Integrated Circuit	Fairchild U637741393
U2	Integrated Circuit	Fairchild U637741393
U3	Integrated Circuit	Fairchild U6E7741393

Reference Number	Part Name	Rating-Remarks
U4	Integrated Circuit	Fairchild U6E7741313
U5	Integrated Circuit	Fairchild U5B7725333
U6	Integrated Circuit	Fairchild U5B7725333
C6	Capacitor	.01mf CK05-06 Aerovox MC51C 103RK
C7	Capacitor	.01mf CK05-06 Aerovox MC51C 103RK
C8	Capacitor	.01mf Ck05-06 Aerovox MC51C 103RK
C9	Capacitor	.01mf CK05-06 Aerovox Mc51C 103RK
R46	Resistor 1/8w	10K 1% 1/8w IRC CEA-
R49	Resistor 1/8w	10K 1% 1/8w IRC CEA-
R47	Resistor 1/8w	90.9K 1% IRC CEA T-0
R48	Resistor 1/8w	90.9K 1% IRC CEA T-0
R26	Pot. 10T	10K IRC HD 150
R7	Pot. 10T	5K IRC HD150
R6	Resistor 1/4w	402Ω IRC RN60B/D 1/4w
VRL	Zener diode	IN961B
R54	Resistor	270Ω 1/4w Carbon 5%
R55	Resistor	270Ω 1/4w Carbon 5%
C19 (C20)	Capacitor	.001mf
R50	Resistor	3010Ω RN60B/D IRC
S2	Switch	Toggle DPDT. 28, 1 amp
R51	Resistor	10K RN55D IRC CEA-TO
R2	Resistor	1K RN55D IRC CEA-TO
C18	Capacitor	1.0mf Component Research Co. 03PG105DN
R8	Resistor	10K RN55D IRC CEA-TO

Reference Number	Part Name	Rating-Remarks
R7	Pot. 10T	10K IRC HD150
R9	Resistor 1/8w	13.3K RN55D IRC CEB-TO
R6	Resistor 1/4w	750Ω RN60B/D IRC CEB-TO
R52	Resistor 1/4w	750Ω RN60B/D IRC CEB-TO
R11	Resistor 1/8w	10K RN55D IRC CEA-TO
R5	Resistor 1/8w	10K RN55D IRC CEA-TO
R12	Resistor 1/4w	10K 1/4w Carbon 5%
R15	Resistor 1/4w	2.5K RN60B/D IRC-CEB-TO
R3	Resistor 1/8w	175K
R40	Resistor 1/8w	100K
R1	Resistor 1/8w	100K
R41	Pot. 10T	500K IRC HD-150
R42	Pot. 10T	500K IRC HD-150
C1	Capacitors	2-1mf 2-5mf 2-20mf
C2	Capacitors	2-1mf 2-5mf 2-20mf
D1	Diode	IN4001
Q1	Transistor	AN4234
ZR3	Diode	IN3788
R53	Resistor	100Ω, 1 watt Carbon
TP1-TP20		Test Points
R21A	Resistor 1/8w	6040Ω RN55 IRC CEA TO
ZR4	Diode	IN758A
C21	Capacitor	.9omf Non-polarized
R50C	Resistor	100K
R40C	Resistor 1/8w	100K
R41C	Pot. 10T	500K IRC HD-150

Reference Number	Part Name	Rating-Remarks
R51C	Resistor	10K
R52C	Resistor	200 Ω
R53C	Resistor	36 Ω
R54	Resistor	200K
TR1	Thermistor	YSI-44011 100K at 25°C
TR2	Thermistor	4 ea YSI 44011 in series ea 100K at 25°C
R1	Resistor 1/8w	59K 1% RN55D
R2	Resistor 1/8w	59K 1% RN55D
R3	Resistor 1/8w	59K 1% RN55D
R4	Resistor 1/8w	280K 1% RN55D
R5	Resistor 1/8w	280K 1% RN55D
R6	Resistor 1/8w	280K 1% RN55D
R7	Resistor 1/2w	2.15K 1% RN60B/D
R8	Resistor 1/2 w	2.26K 1% RN60B/D
Z1	Zener Diode	IN968B Motorola
Z2	Zener Diode	IN961B Motorola
C1	Capacitor	.01mf CK05-06 Aerovox MC51C103RK
30	Transducer	Model 69Ta-2A Current to Air Transducer-Foxboro Co. Foxboro, Mass.

In summary, the bridge circuit output signals are amplified by amplifiers U6 and U5 and then amplified and summed by amplifier U-4 to yield a voltage proportional to "mean body temperature." The weight given each temperature, ear and skin, is determined by the gain settings for U5 and U6. A voltage proportional to the desired mean body temperature set point is provided by the "preset" circuit. The output of the summing amplifier U4 is fed into amplifier U2 whose output

is proportional to time rate of change of mean body temperature and into U1 whose output is proportional to mean body temperature. The output of U1 and U2 are summed at the input to U3, an inverting amplifier. A "manual input," or bias, can be introduced by the potentiometer R7. The output of amplifier U3 is fed into the electro-pneumatic transducer 30 whose output may be a 3-15 psig air source with pressure proportional to input voltage. This air source controls the flow through a diverter valve 24 in Fig. 1. Changes in core and skin temperature are amplified, summed, and converted to a diverter valve command proportional to the deviation of the summed signal from a set point value and to the rate of change of the summed signal from its set point. The electro-pneumatic transducer 30 and diverter valve 24 act as the links between the controller 32 and the fluid system shown in Fig. 1.

Although only one preferred embodiment of the invention has been described herein, many other variations will be apparent to those skilled in the art. It is therefore intended that the scope of the invention be limited only by the claims which follow.